EP 33730 (c)

# (12) UK Patent Application (19) GB (11) 2 348 336 (13) A

(43) Date of A Publication 27.09.2000

(21) Application No 9906666.4

(22) Date of Filing 24.03.1999

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(51) INT CL[7]
**H04R 7/18 , F16K 7/12 , H04R 9/02 9/06**

(52) UK CL (Edition R )
**H4J JDM J30F J31H**
**F2V VG1**

(56) Documents Cited
**GB 2035008 A** **GB 0726780 A** **GB 0393313 A**
**GB 0347852 A** **EP 0823828 A2** **US 5740264 A**
**US 1732351 A**

(58) Field of Search
**UK CL (Edition Q ) F2V VG1 , H4J JCA JDM JDP**
**INT CL[6] F16K 7/12 , H04R 7/16 7/18 7/20 9/00 9/02 9/06 31/00**
**ONLINE: WPI, EPODOC, JAPIO**

(54) Abstract Title
**A suspension for diaphragm actuators**

(57) The diaphragm actuator 22 comprises a diaphragm 24, a motive means 26,27 arranged to move the diaphragm axially 23, and a flexible suspension 30 that constrains the movement of the diaphragm 24 and which extends around a periphery of the diaphragm 24 and which arches 31,32 in one axial direction between the diaphragm 24 and a relatively rigid carrier 35. The span 31 and/or height 32 of the arched suspension varies repeatedly around the periphery of the diaphragm 24.

This arrangement is useful with loudspeakers and fluid or gas control valves.

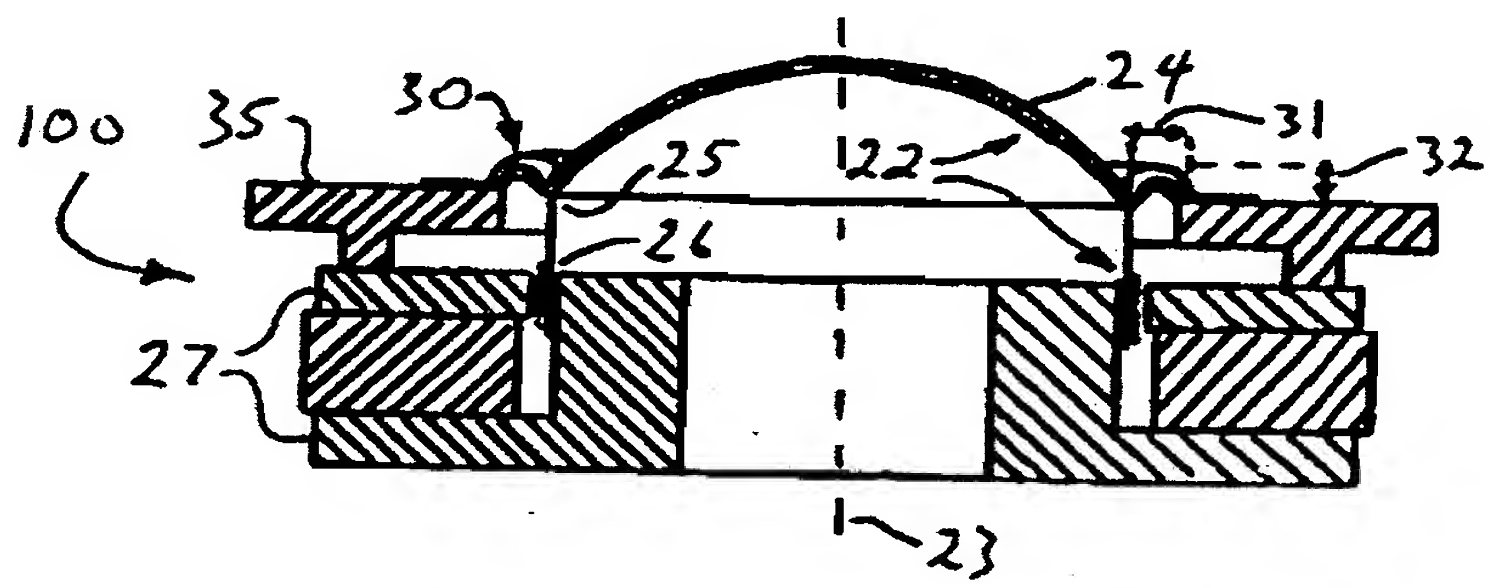


Fig. 3

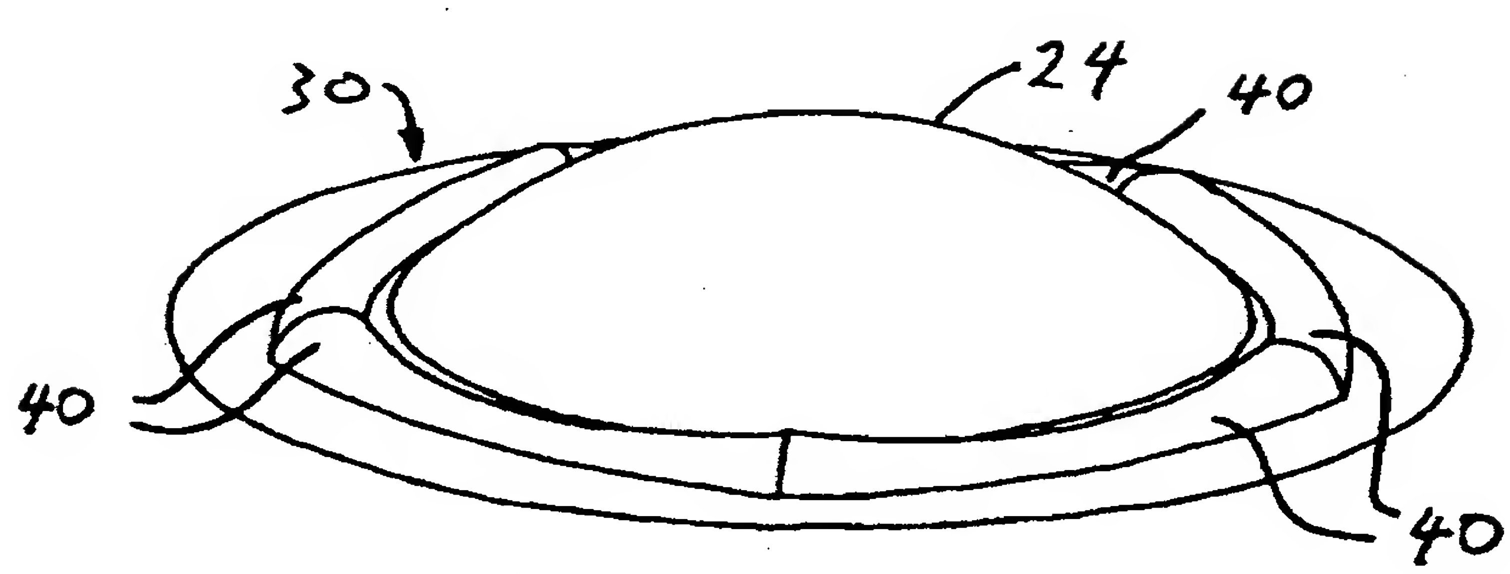


Fig. 4

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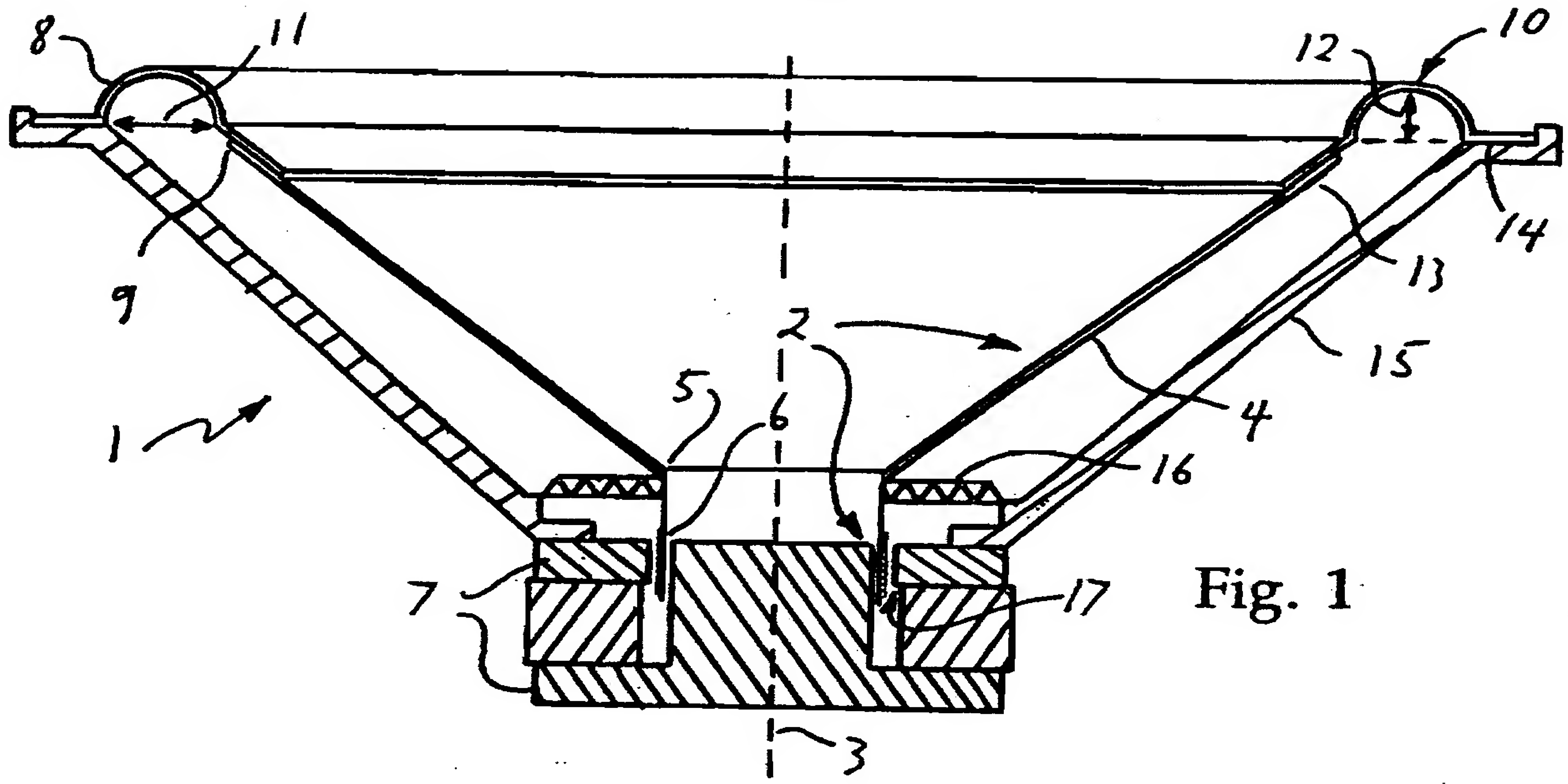


Fig. 1

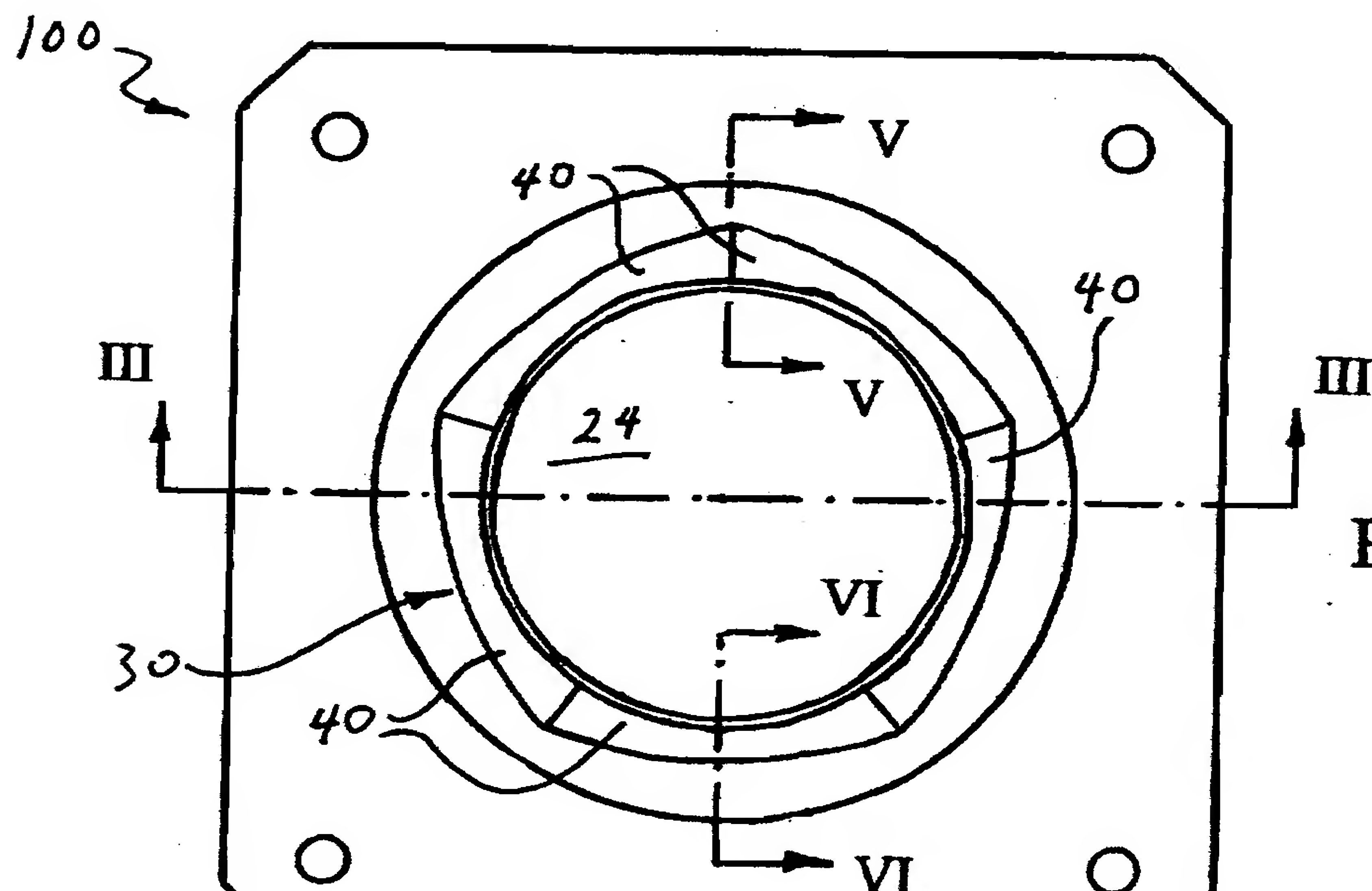


Fig. 2

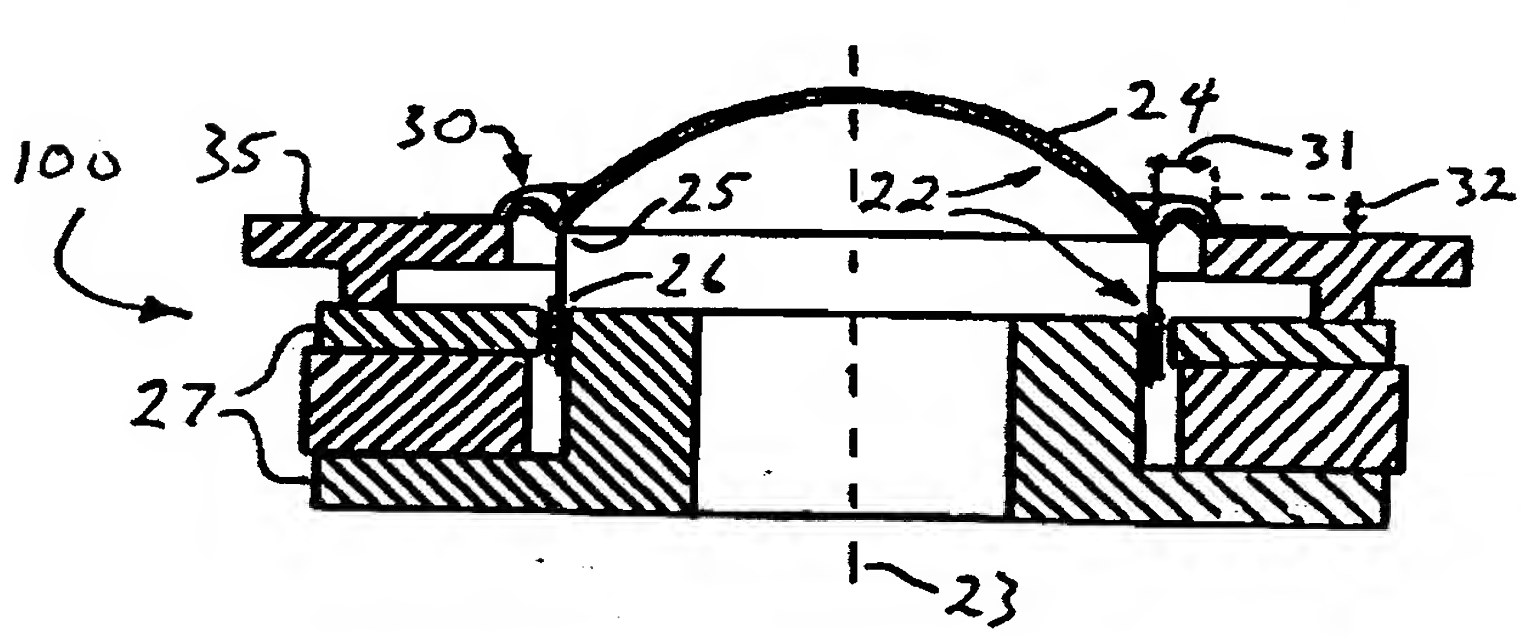


Fig. 3

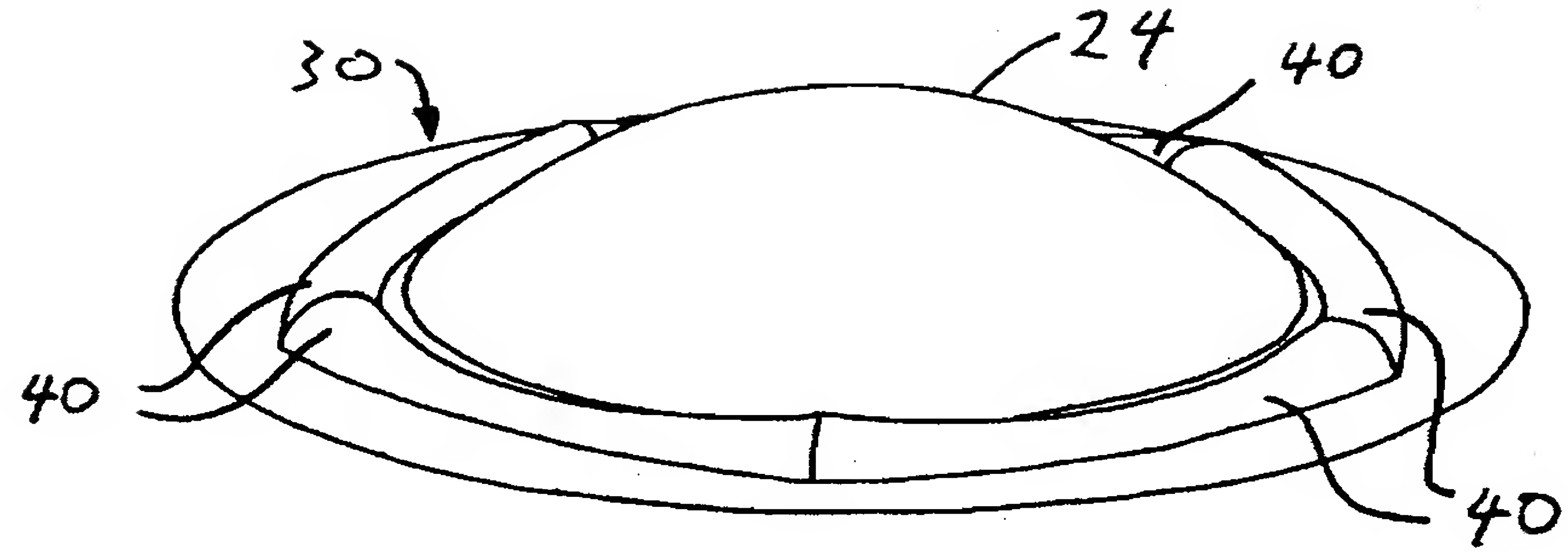


Fig. 4

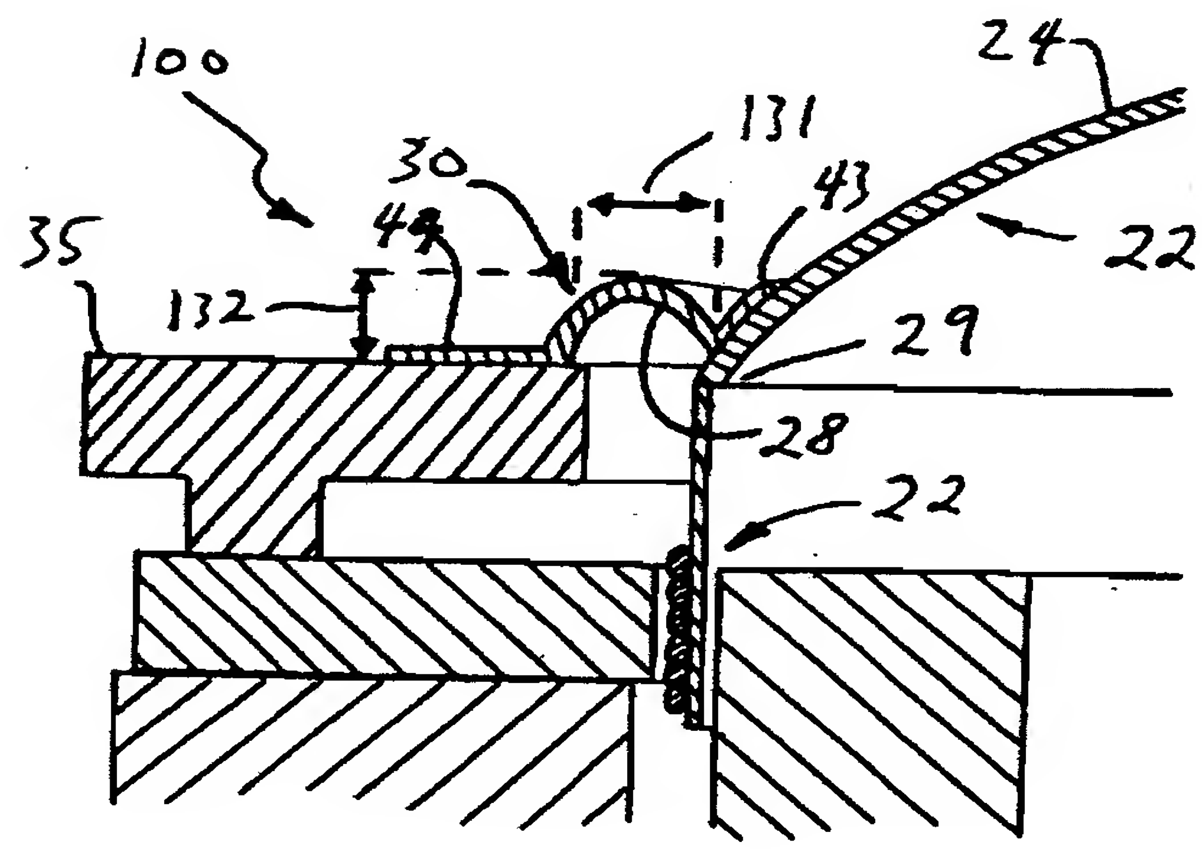


Fig. 5

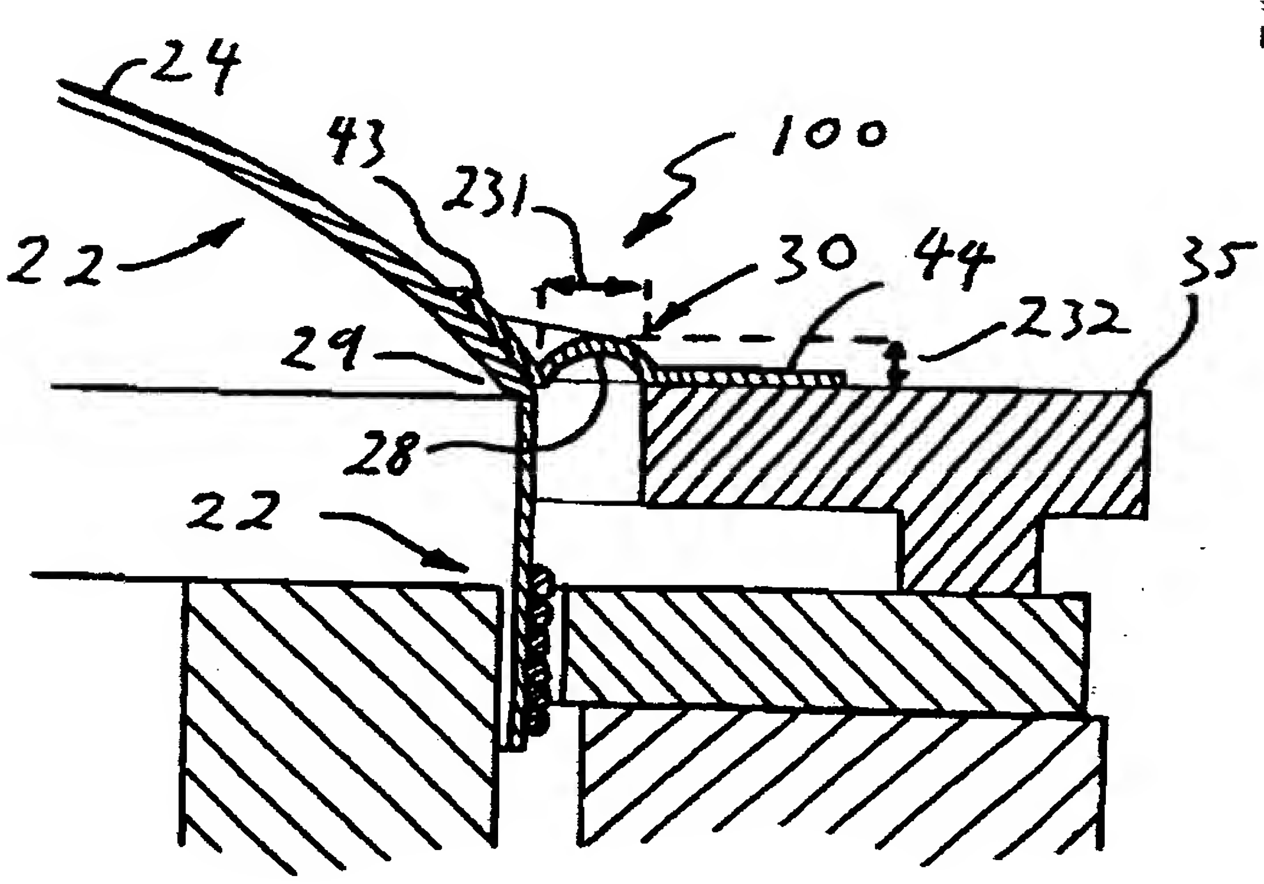


Fig. 6

# Diaphragm Actuators

The present invention relates to diaphragm actuators, and in particular to diaphragm actuators used in audio sound reproduction equipment, for example loudspeakers and microphones, and also to positional servomechanisms including fluid or gas control valves, for example diaphragm fuel control valves for aero-engines.

Diaphragm actuators come in many forms. Loudspeaker usually have a flexible concave frustoconical diagram actuated by a motor in the form of an electromagnetic coil attached to the diaphragm at an inner periphery of the truncated cone, which typically has a circular or elliptical periphery. The diaphragm is flexibly suspended at the outer periphery of the cone to a rigid frame or carrier. The flexible suspension usually takes the form of a symmetrical band of rubber or other elastomeric material. The flexible suspension is rolled or folded so that there is an excess of material between the diaphragm and the surrounding carrier, thereby permitting axial movement of the diaphragm when driven by the coil.

Other types of loudspeaker such as those having a relatively rigid diaphragm, which may be part spherical and concave or convex, use the same type of rolled or folded flexible suspension.

Fluid control valves in aero-engines may also use a diaphragm actuator, which may be a membrane with a surrounding flexible suspension that permits the diaphragm to move relative to a valve seat.

In normal circumstances flexible suspension of this type move in such a way that the edge of the flexible suspension, where it is attached to the diaphragm, moves

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with the same velocity and acceleration as the diaphragm itself, and the movement gradually and uniformly decreases across the suspension until it falls to zero at the point where the suspension is attached to the rigid carrier. Ideally, the energy of vibration transmitted from the diaphragm into the suspension is gradually absorbed in the material of the suspension so that no energy is reflected back from the fixed attachment. In practice, however, some energy can be reflected anti-phase back into the diaphragm by the boundary at the junction between the flexible suspension and the carrier.

It is known that suspensions of these types can exhibit energy storage in the form of radial standing-waves in circumstances where the effective path length which the suspension presents to vibrational energy in the material of the suspension travelling out from the diaphragm to the attachment point at the carrier corresponds to certain fractions or multiples of the wavelength $\lambda$ of the vibration in the material from which the flexible suspension is formed. These standing waves modify the movement of the suspension so that nodes of lesser movement and anti-nodes of greater movement occur periodically across the radial width of the flexible suspension. In effect the energy entering the suspension at vibrational wavelengths of these significant dimensions is no longer substantially absorbed, but part reflects back from the rigid carrier and interferes constructively with further incoming energy waves. This produces alternate regions of cancellation and reinforcement across the radial width of the suspension, a condition commonly known as self-resonance. In general, the strongest standing wave will occur at a frequency where the effective path length across the flexible suspension corresponds to $\lambda/2$, when the suspension will effectively

move in anti-phase to the diaphragm, with the next strongest at $3\lambda/2$.

It is also known that such self-resonance in the flexible suspension has detrimental effects on the performance of systems of this type. In the case of loudspeakers the effect may be to degrade the accurate reproduction of sound. This is a particular problem with rapidly changing or short duration input signals. In the case of positional servomechanisms, such as diaphragm fuel-control valves in aero-engines, the effect may be to prevent the desirable rapid settling of the diaphragm at a new control position. In some cases where the power input to the system is large, the standing waves in such flexible suspension may even become violent enough to cause damage such as splitting of the suspension itself, or of a join between the suspension and the diaphragm.

A number of approaches have been proposed to overcome or mitigate these problems.

One approach is to make the suspension narrow so that the effective path length across the suspension becomes small relative to impinging wavelength. Standing waves will then not form at any frequency within the working frequency range of the actuator. This solution cannot be applied to diaphragm actuators such as loudspeakers which must permit substantial piston amplitude and which are intended to cover a broad frequency range.

Another approach is to manufacture the suspension from a material having high internal energy dissipation, or to treat the suspension with energy absorbent coatings, fillers or impregnated compounds. This solution has the disadvantage that the level of energy absorbency which will properly control high frequency standing waves in the

suspension will also over-damp low frequency movement of the diaphragm. Normally a compromise is adopted which gives good low frequency behaviour while suppressing standing wave formation up to some reasonably acceptable frequency. For speakers intended for use over a very wide audio band, such compromises are a barrier to high accuracy. Even when very good prevention of standing wave formation is achieved there still remains an increasing tendency to wave formation at certain frequencies where the correct relationships are achieved between wavelength and the effective path length across the radial width of the flexible suspension. The high absorbency of the suspension results in more energy dissipated within the suspension at those frequencies, and a variation in speaker output may result as a change in spatial distribution of sound output.

Yet another approach is to manufacture a composite flexible suspension where the material adjacent to the diaphragm is of high energy absorbing ability and the portion of the suspension adjacent to the supporting structure is of a low absorption, free moving material. This combines good standing wave suppression with good low frequency freedom of motion. However, such suspensions are costly to make and incorporate a potentially unreliable bond in a position of high stress in the suspension. Where the dissimilar materials are welded together or co-moulded to avoid an unreliable bond, the process costs are high. Again, the high absorbency of the suspension adjacent the diaphragm means that more energy will be dissipated within it at those frequencies, and a variation in speaker output may result as a change in spatial distribution of sound output.

It is also known in the design of loudspeakers to vary the properties of a flexible resilient suspension between a

diaphragm and a surrounding support. Patent document GB 2,297,454 A discloses a loudspeaker in which the outer edge of a conical diaphragm has been clipped to vary the overlap between an otherwise uniform flexible suspension and a conical diaphragm. This has the effect of reducing self-resonance, but with the disadvantage that the bond between the suspension and diaphragm will be weaker in areas of reduced overlap.

Another approach is disclosed in US 4,324,312 in which a flexible metal suspension has alternately concave and convex diamond-shaped folds. This allows a constant degree of overlap, but this design suffers from other limitations. Such a suspension may be arranged to have high stiffness to self-resonance across its radial width at the detrimental frequency where the effective path length across the suspension approaches half the wavelength of the impinging waves. Standing modes may thereby be prevented. At higher frequencies however, the increased stiffness becomes insufficient to prevent standing wave formation. This method cannot be used for devices operating over very wide frequency ranges, particularly those required to work at low frequencies where the limited flexibility of a metal suspension prevents the attainment of sufficient movement.

Any proposal for the elimination of standing waves should ideally maintain other functions of diaphragm actuator suspensions, which may be listed as:

a) Stabilisation of diaphragm motion so that the diaphragm axis remains parallel to its axial motion.

b) Centering of the moving components of the diaphragm motor relative to fixed components to prevent noise generation and friction wear failures.

c) Achieving a linear restoring force with increasing drive amplitude to avoid distortion of the transduced wave form.

d) Setting and maintaining the correct rest position of the moving system so that motor and suspension symmetry are preserved.

e) Sealing of the edge of the diaphragm actuator to prevent waves radiated by the rear face of the diaphragm cancelling those radiated from the front.

It is an object of the invention to provide a diaphragm actuator that addresses these issues.

Accordingly, the invention provides a diaphragm actuator, comprising a diaphragm, a motive means arranged to move the diaphragm axially, and a flexible suspension that constrains the movement of the diaphragm and which extends around a periphery of the diaphragm and which arches in one axial direction between the diaphragm and a relatively rigid carrier, wherein the span and/or height of the arched suspension varies repeatedly around the periphery of the diaphragm.

The diaphragm will comprise a sheet, layer, membrane, et cetera. The movement of the diaphragm by the motive means will be movement of the diaphragm out of the plane or surface defined by the sheet, layer or membrane. The direction of movement therefore defines an axis, which may also correspond with an axis of symmetry of the diaphragm. If the diaphragm is a flat sheet, then the axis may be a normal to the sheet.

The varying span and/or height of the arches allow the distance through the material of the suspension between the diaphragm and the carrier to vary in like manner. The waves or vibrations entering the suspension from the diaphragm at adjacent points, or reflected at adjacent points on a boundary between the suspension and the carrier, will therefore tend to form crests and troughs at different radial distances across the arched suspension. It is thus possible to reduce or avoid self-resonance owing to constructive interference between such waves or vibrations.

The varying dimensions of the arch also permit any join or overlap between the suspension and the diaphragm to have substantially uniform characteristics around the circumference of the diaphragm.

Usually the motive means is on one side of the diaphragm, for example being a voice coil arranged to interact with a permanent magnet. In this case, the axial direction in which the suspension arches will usually be in a direction away from the motive means. The suspension may however, arch in the opposite direction, i.e. in an axial direction towards the motive means,

In a preferred embodiment of the invention, the repeated variation of the span and/or height of the suspension defines a plurality of sections around the periphery of the diaphragm, each section being similar to the or each other section. In this way, the resonance damping ability of the suspension is distributed around the periphery of the suspension.

There may be an even number or an odd number of sections. Preferably, there are an odd number of sections so that resonant behaviour at a first point around the

circumference is not mirrored by similar resonant behaviour at a second point diametrically opposite the first point. This may facilitate destructive interference in any modes of self-resonance having a node or anti-node along a line passing through the centre of the diaphragm.

The variation may also be an integral number of at least two periodic continuous changes of arch type. The arch may be a double arch, in which case the effective span is a total span and the effective height is a maximum height of one of the arches. For example the section profile of the arch may vary between a single arch having a half roll and a double arch having two half rolls with a groove of varying depth and radial position between the two arches.

Usually, there will be just one arch. The arched diaphragm may have just a variable span, with a relatively constant height, or vice versa. However, it is preferable, in order to increase the difference between the maximum and minimum distance through the suspension between the diaphragm and the carrier, if both the span and height of the arched suspension vary together, and preferably in unison.

The arch may have any type of arched shape, including a plurality of sections one or more of which may be substantially flat. The shape of the arch at each point around the periphery of the suspension may advantageously be an arc of a circle. Such curved arches avoid concentration of stress along cusps and edges. Then, as the span and height of the arched suspension varies, so also will the radius of the circle vary around the periphery of the suspension.

In a preferred embodiment, the span and/or height of the arched suspension varies gradually at local minimum of the span and/or height. Also, the span and/or height of the

arched suspension varies rapidly at a local maximum of the span and/or height.

The suspension may be resilient, for example being formed from an elastomeric material. This in general will permit a greater degree of movement than other types of suspension, for example those made from a metal.

The invention will now be described in further detail by way of example only and with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view of a conventional loudspeaker having a flexible suspension of arched half roll profile having a constant radial span and axial height;

Figures 2 shows a plan view of a loudspeaker comprising a diaphragm actuator according to the invention;

Figure 3 shows a cross-section through the loudspeaker of Figure 2, taken along line III-III, showing a flexible edge suspensions surrounding the periphery of a central diaphragm;

Figures 4 shows a perspective view of the suspension and diaphragm of the loudspeaker of Figure 2; and

Figures 5 and 6 show cross-sections through the flexible edge suspension, taken respectively along lines V-V and VI-VI.

Figure 1 shows a loudspeaker 1, having a conventional diaphragm actuator 2 comprising about a central axis 3 a truncated conical diaphragm 4, connected at an inner

periphery 5 to a motive means in the form of a voice coil motor 6 and permanent magnet 7. When current is passed through the voice coil 6, the voice coil moves the conical diaphragm 4 axially along the axis of symmetry 3 of the conical diaphragm 4.

The movement of the diaphragm 4 is constrained mainly by a flexible suspension 10 about an outer periphery 9 of the diaphragm 4. The diaphragm has a single arch 8 of a uniform cross-sectional shape, having a constant span 11 in a radial direction and a constant height 12 in an axial direction. The suspension 10 joins the diaphragm outer periphery 9 at a constant overlap 13, and is similarly joined to a surrounding rigid carrier frame 15 at another overlap 14. The arch 10 is thus bounded by the overlaps 13,14.

Some constraint to movement of the diaphragm 4 also comes from an annular corrugated fabric ring 16 connecting the diaphragm inner edge 5 to the carrier frame 15. The voice coil 6 is held centrally in a gap 17 in the magnet 7 by the combined action of the suspension 10 and the corrugated ring 16.

The suspension 10 is chosen to be a material of suitable internal friction to achieve a compromise between low and high frequency performance. At low audio frequencies, e.g. between 20 Hz and 2 kHz, depending on the particular diameter and construction of the loudspeaker 1, the material halfway across the suspension 10 will move in phase with the diaphragm 4 but with about half the amplitude of the diaphragm 4 itself. At higher frequencies, significant energy can be stored in the suspension 10 in the form of waves travelling from the diaphragm outer edge 9 to the carrier frame 15, and then reflected antiphase back through the suspension into the

diaphragm 4. The behaviour of the waves in the material of the suspension 10 will be a function of many parameters, including the frequency and amplitude of the diaphragm movement, the density, elasticity, thickness and particular shape of the suspension 10, the ability of the material of the suspension 10 to absorb such waves, and the radial position between the diaphragm 4 and carrier frame 15. These parameters collectively define the effective acoustic path length across the suspension in terms of a number or fraction of wavelengths of such waves entering the suspension 10.

At a frequency where the energy entering the suspension 10 from the movement of the diaphragm 4 has a wavelength exactly twice the effective path length through the suspension 10 from diaphragm to carrier frame 15, a standing wave will occur in which the material at the halfway point moves in antiphase to the diaphragm 4. This will cause the output of the loudspeaker 1 to fall at that frequency. Because the loudspeaker 1 is radially symmetrical the same effect occurs all around the suspension and is therefore powerfully promoted. The only mechanism acting to mitigate this undesirable problem is the ability of the suspension material to absorb vibrational energy and dissipate it as heat, a process commonly called damping. Unfortunately, materials which maximise this damping property also have high internal friction losses, thereby exerting a frictional restraining effect on diaphragm movement at lower frequencies, thus making it difficult to extend the output of the loudspeaker 1 at the lower end of its frequency range.

The varying geometrical relationship between portions of the complete moving system undergoing opposing motions can also cause variations in the spatial distribution of output. Finally, and possibly most undesirably, energy

will effectively be stored in the material of the suspension and released later as time smeared output which bears no relationship to the applied signal.

In such conventional typical midrange (e.g. 2 to 5 kHz) and high frequency (e.g. 5 to 20 kHz) loudspeakers the effect of self-resonance in the suspension can only be mitigated by using suspensions manufactured from materials with high damping capability with attendant loss of the ability to move freely at low frequencies, or by making the suspension very narrow so that the self-resonances occur only at higher frequencies so that the small area of the suspension compared to the larger diaphragm area limits the degree to which self-resonances affect the output of the loudspeaker. This second approach further limits the ability of the loudspeaker to radiate at low frequencies because a narrow surround is inherently stiffer and therefore raises the low frequency cut-off point of the loudspeaker.

Figures 2 to 6 show various views of one embodiment the invention, in which a loudspeaker 100 has a diaphragm actuator 22 according to the invention. The diaphragm actuator 22 comprises about a central axis 23 a rigid part-spherical convex diaphragm 24 formed from a carbon fibre composite material. The diaphragm 24 is connected at an inner periphery 25 to a motive means in the form of a voice coil motor 26 and permanent magnet 27. When current is passed through the voice coil 26, the voice coil moves the diaphragm 24 axially along the axis of symmetry 23 of the part spherical diaphragm 24.

The movement of the diaphragm 24 is constrained by a flexible suspension 30 about an outer periphery 29 of the diaphragm 24. The embodiment may, however, provide additional means to constrain partly the movement of the

diaphragm 24, such as the corrugated suspension 16 of Figure 1.

The suspension 30 has a single arch 28 formed from five similar sections 40 each having a span 31 and height 32 that varies between a maximum 131,132 at the points where the sections adjoin as shown in Figure 5, to a minimum 231,232 at the middle of each section as shown in Figure 6. The span 31 and height 32 of the arch 30 therefore varies repeatedly around the periphery of the diaphragm 24.

The suspension 30 joins the diaphragm outer periphery 29 at a constant overlap 43, and is similarly joined to a surrounding rigid carrier frame 35 at another overlap 44. The arch 30 is thus bounded by the overlaps 43,44. The inner constant overlap 43 provides a constant bond between the diaphragm 24 and the suspension 30. Differences in span width can be taken up by the exact positioning of the outer overlap 44 on the surrounding carrier frame 35 and/or the inner overlap 43 on the diaphragm 24.

The path length of the flexible suspension 30 between the diaphragm 24 and the carrier frame 35 varies around the periphery of the diaphragm 24 according to the span 31 and height 32 of the suspension 30. Therefore, for a given frequency, waves within the suspension at differing points around the periphery of the suspension 24 will not all reinforce constructively for that frequency. An odd number of sections 40 prevents the possibility of the diaphragm 24 rocking about potential diametrical axes formed by opposite sections 40 of the suspension 30 having the same arch dimensions.

The speaker described above may have a diaphragm diameter of 50 mm with a peak of the domed diaphragm rising 15 mm.

The minimum and maximum dimension of the suspension for each section can vary between a span of 3 mm to 6 mm, and a height of 3 mm to 6 mm. Such a speaker has an acoustical output without perturbations caused by self-resonance of the flexible suspension over the range from 200 Hz to 20 kHz.

The suspension 30 may be economically made from an elastomeric material, for example a synthetic nitrile rubber, where accurate response to an electrical signal is required over a wide range of frequencies. The shape may be formed by a stamping process in a mould at elevated temperatures sufficient to impart the shape of the mould into the suspension. The diaphragm can be symmetric, for example circular or elliptical, and this together with an even bond between the diaphragm and suspension can help provide an even output response for the diaphragm. Such a diaphragm may be useful in a wide range of applications, including loudspeakers, microphones and fuel control valves, where an even output and accurate response is required over a wide range of frequencies.

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Claims

1. A diaphragm actuator, comprising a diaphragm, a motive means arranged to move the diaphragm axially, and a flexible suspension that constrains the movement of the diaphragm and which extends around a periphery of the diaphragm and which arches in one axial direction between the diaphragm and a relatively rigid carrier, wherein the span and/or height of the arched suspension varies repeatedly around the periphery of the diaphragm.

2. A diaphragm actuator as claimed in Claim 1, in which the motive means is on one side of the diaphragm and the suspension arches in an axial direction away from the motive means.

3. A diaphragm actuator as claimed in Claim 1 or Claim 2, in which the repeated variation of the span and/or height of the suspension defines a plurality of sections around the periphery of the diaphragm, each section being similar to the or each other section.

4. A diaphragm actuator as claimed in Claim 3, in which there are an odd number of sections.

5. A diaphragm actuator as claimed in any preceding claim, in which the span and height of the arched suspension varies in unison.

6. A diaphragm actuator as claimed in Claim 5, in which the shape of the arch at each point around the periphery of the suspension is an arc of a circle.

7. A diaphragm actuator as claimed in Claim 6, in which the radius of the circle varies around the periphery of the suspension.

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8. A diaphragm actuator as claimed in any preceding claim, in which the span and/or height of the arched suspension varies gradually at local minimum of the span and/or height.

9. A diaphragm actuator as claimed in any preceding claim, in which the span and/or height of the arched suspension varies rapidly at a local maximum of the span and/or height.

10. A diaphragm actuator as claimed in any preceding claim, in which the suspension is formed from an elastomeric material.

11. A positional servomechanism comprising a diaphragm actuator, in which the diaphragm actuator is as claimed in any preceding claim

12. A loudspeaker comprising a diaphragm actuator, in which the diaphragm actuator is as claimed in any of Claims 1 to 10.

13. A diaphragm actuator substantially as herein described, with reference to Figures 2 to 6 of the accompanying drawings.

14. A positional servomechanism substantially as herein described, with reference to Figures 2 to 6 of the accompanying drawings.

15. A loudspeaker substantially as herein described, with reference to or as shown in Figures 2 to 6 of the accompanying drawings.

**Application No:** GB 9906666.4
**Claims searched:** 1 to 12

**Examiner:** Peter Easterfield
**Date of search:** 21 June 1999

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): F2V (VG1); H4J (JCA, JDM, JDP)

Int Cl (Ed.6): F16K 7/12; H04R 7/16, 7/18, 7/20, 9/00, 9/02, 9/06, 31/00

Other: Online: WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| X | GB 2035008 A | (LANSING) | 1-3,9,12 |
| X | GB 0726780 A | (COLE) | 1-3,9,12 |
| X | GB 0393313 A | (ABRAHAMS) | 1-3,9,12 |
| X | GB 0347852 A | (LIMIT) | 1-3, 9,12 |
| X | EP 0823828 A2 | (MATSUSHITA) | 1-3, 9,10,12 |
| X | US 5740264 A | (KOJIMA) | 1,10,12 |
| X | US 1732351 A | (BORKMAN) | 1-3,9,12 |

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| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
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